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# MODELS OF THE MAGNETIC FIELD EVOLUTION IN SUPERNOVA REMNANTS

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**Abstract.** In this paper we present a brief discussion of the magnetic field ($H$) evolution in supernova remnant (SNRs). Evolution models generally assume $H \propto D^{-\delta}$. Knowing $\delta$ would be particularly important in the study of the radio surface brightness to diameter ($\Sigma - D$) relation for SNRs, since it would allow us to compare different theoretical models for the radio evolution.

## 1. INTRODUCTION

An important characteristic of supernova remnants (SNRs) is their dominant synchrotron emission in the radio domain of electromagnetic spectrum. This kind of emission is powered via relativistic electrons in magnetic field. Typical value for the ISM magnetic field is 5 $\mu$G. In order to explain the luminous synchrotron emission from SNRs we need much higher values for the magnetic field strength, so the field must have been somehow amplified. Details of magnetic field amplification and synchrotron mechanism in SNRs, i.e. their radio (synchrotron) evolution and a possible radio surface brightness to diameter ($\Sigma - D$) relation, are still not well understood. In order to understand better this evolution we must also know the magnetic field evolution, i.e. the magnetic field strength to diameter ($H - D$) dependence. We will briefly discuss different magnetic field evolution models.

## 2. DISCUSSION

Historically, derivations of different $\Sigma - D$ relations assumed different magnetic field evolution models, but they all followed the power law form

$$H \propto D^{-\delta}. \tag{1}$$

Table 1: History of $H \propto D^{-\delta}$ models in derivation of the $\Sigma - D$ relation.

| Author(s) | year | value for $\delta$ |
|---|---|---|
| Shklovsky | 1960 | 2 |
| Lequeux | 1962 | 1 |
| Poveda & Woltjer | 1968 | 0 |
| Kesteven | 1968 | 1 |
| Duric & Seaquist | 1986 | $1.5 \leq \delta \leq 2$ |

Shklovsky (1960) was the first who theoretically analyzed the synchrotron radiation for a spherical expanding nebula (for the purpose of deriving the theoretical $\Sigma - D$ relation). He used the magnetic field model (1) with $\delta = 2$. In subsequent years, different authors assumed different values for $\delta$ (see Table 1). Finally, Duric and Seaquist (1986) used the magnetic field model proposed by Gull (1973) and Fedorenko (1983), i.e. $1.5 \leq \delta \leq 2$.

We would expect $\delta = 2$ if the magnetic field has been amplified at some moment during the early evolution of an SNR and it remained "frozen" in plasma according to Alfven's theorem,

$$HD^2 = \text{const.} \tag{2}$$

This may be the case if the field has been amplified due to the Rayleigh-Taylor (R-T) instability at the contact discontinuity between the shocked ejecta and swept-up ISM.

However, it is more likely that amplification occurs, together with particle acceleration, at the shock front. Recent considerations (see e.g. Berezhko and Völk, 2004) thus support the idea that a fraction of shock kinetic energy is converted into accelerated particles and (amplified) magnetic field energy. If

$$H^2 \propto K \propto \rho V_s^2, \tag{3}$$

in the Sedov's phase ($V_s \propto D^{-3/2}$), we have $\delta = 1.5$. $K$ is the parameter from the power-law electron spectrum $N(E)dE = KE^{-\Gamma}$, $\rho$ is density behind the shock and $V_s$ is shock velocity.

This model also implies the equipartition between the magnetic field and cosmic rays energy. In the true equipartition

$$\epsilon_H = \epsilon_{\mathrm{CR}}, \tag{4}$$

while the revised Pacholczyk's (1970) minimum-energy formula (see Beck and Krause, 2005) gives

$$\epsilon_H = (\Gamma + 1)/4 \; \epsilon_{\mathrm{CR}}. \tag{5}$$

At later stages in the evolution we expect $H = \text{const}$, i.e. magnetic field is simply amplified interstellar field and $\delta = 0$. We can see, in the end, that different values for $\delta$ arise from different models, but they would also differ for different evolutionary phases. Knowing $\delta$ would allow us to compare different theoretical models for the radio evolution and a possible way to estimate the evolutionary status of SNRs, in combination with the $\Sigma - D$ relation.

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